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Engineer's Refractive Effects Prediction System (EREPS)

Revision 1.00 User's Manual

H. V. Hitney
A. E. Barrios
G. E. Lindem

NAVAL OCEAN SYSTEMS CENTER
San Diego, California 92152-5000

E. G. SCHWEIZER, CAPT, USN
Commander

R. M. HILLYER
Technical Director

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Procedures are described for utilizing the three IBM-PC programs presented. These programs constitute Revision 1.00 to the Engineer's Refractive Effects Prediction System (EREPS), which is used in assessing the electromagnetic propagation effects of the lower atmosphere on radio wave transmissions.

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1.0 INTRODUCTION

The Engineer's Refractive Effects Prediction System (EREPS) is a collection of individual programs that have been designed to assist an engineer in properly assessing electromagnetic propagation effects of the lower atmosphere on proposed radar, electronic warfare, or communication systems. Revision 1.00 consists of three individual IBM-PC programs named PROPR, SDS, and RAYS. PROPR generates a plot of path loss, propagation factor, or radar signal-to-noise ratio versus range for a variety of environmental conditions from which signal levels relative to a specified threshold or maximum range can be determined. SDS displays an annual historical summary of evaporation duct, surface-based duct, and other meteorological parameters for many 10- by 10-deg squares of the earth's surface. SDS is the primary source of environmental inputs to PROPR. RAYS is a raytrace program that shows altitude-vs.-range trajectories of a series of rays for any user-supplied refractive-index profile, and includes an option to display altitude error relative to a standard atmosphere.

EREPS contains many similarities to the Integrated Refractive Effects Prediction System (IREPS) described by Patterson et al. [1] that has been used by the United States Navy and other organizations since 1978 for operational propagation assessment. However, there are fundamental differences between EREPS and IREPS. IREPS was developed to provide operational assessment to a wide variety of existing equipments by means of *in situ* measured environmental data. Much of the program deals with maintaining libraries of existing systems parameters and entering divergent sources of environmental data. IREPS is not well suited to comparing the performance of two sensors that may differ by only one parameter, such as radar pulse length, or to showing relative performance for a given system as one environmental parameter, such as wind speed or evaporation duct height, changes value. EREPS has been specifically designed for these comparative studies using interactive graphics displays. Also, EREPS is much better suited than IREPS to long-term statistical performance assessment for a specified area. Finally, the EREPS models have been improved to give better results for low-altitude applications.

The EREPS programs were developed using Microsoft QuickBASIC Version 3.0 and are distributed as compiled executable files. The basic source code is available by special request. Minimum system requirements are one 360-Kbyte floppy drive, 640 Kbytes of memory, and either a CGA or EGA graphics adapter. Problems or inquiries should be addressed to: Code 543, Naval Ocean Systems Center, San Diego CA 92152-5000. Telephone 619-553-1428, Autovon 553-1428, or send electronic mail to herb@nosc.mil.

2.0 BACKGROUND

Refractive index is defined as $n = c/v$, where c is the speed of an electromagnetic wave in a vacuum and v is the speed in the actual medium. Refractive index n at the earth's surface for normal radio frequencies is approximately 1.000350. As a convenience, refractivity N has been defined as $N = (n-1) \times 10^6$, corresponding to 350 at the earth's surface. Refractivity normally decreases with altitude at a rate from 0 to 79 N/km, known as a normal gradient, which causes ray paths to bend downward in space, but at a rate less than the earth's curvature. Any increase in refractivity with altitude is known as a subrefractive gradient and causes a ray path to bend upwards in space. Decreases from 79 to 157 N/km are known as superrefractive gradients and cause a ray to bend down more than normal, but still not as fast as the earth's curvature. Decreases greater than 157 N/km are known as trapping gradients, which cause a ray to curve downward faster than the earth's surface and are responsible for the formation of ducts. As a convenience in determining the presence of trapping layers and ducts, the modified refractivity has been defined as $M = N + (h/a) \times 10^6$, where h is height above the earth and a is the earth's radius. For h in km, $M = N + 157h$ Modified refractivity is very helpful in detecting the presence of trapping layers, since trapping occurs for negative gradients of M with height.

A technique commonly used to account for refraction is to adjust the radius of the earth in calculations to a value such that the electromagnetic ray path becomes a straight line. The relative curvature between the ray and the earth's surface remains unchanged using this technique and calculations of ray trajectory and path-length difference between two rays become greatly simplified. The effective earth radius factor, usually denoted by k, is defined as the effective earth radius divided by the actual earth radius. A value of 4/3 has often been used as a standard value, although over the world's ocean areas the average value is 1.45. The effective earth radius factor concept is valid for subrefractive, normal, and superrefractive gradients, but generally will not work properly for trapping gradients. The value of k is related to N-gradient by $k = 1/[1-a(dN/dh) \times 10^{-6}]$, where a is the earth radius and dN/dh is the refractivity gradient in the same units as a. If dN/dh is given in units of N/km, then $k = 1/(1-0.006371 \times dN/dh)$. For standard refractive conditions, $dN/dh = -39$ N/km and $k = 1.33$.

Trapping gradients can create three principal types of ducts: elevated ducts, surface-based ducts, and evaporation ducts. Elevated ducts are created when a trapping layer is sufficiently high that no rays from a source at the surface will be trapped. Elevated ducts can trap rays only from an elevated source, and hence are most important when assessing airborne systems performance. The source heights for which trapping can occur are from the top of the trapping layer to the height below the trapping layer at which the M-value is the same as at the top of the trapping layer. For source heights above the trapping layer, there will be combinations of ranges and altitudes to which no rays can penetrate. These regions have often been called radio or radar "holes." Although there is a lower frequency limit of ducting associated with the thickness and strength of an elevated duct, for most practical situations the limit is below the normal radar bands, and effects from elevated ducts are therefore considered to be frequency independent. Many of their effects can be illustrated quite well with a raytrace program, such as RAYS. The trapping layer for an elevated duct is usually created by the transition between a cool, moist air mass below and a relatively warm, dry air mass above. Elevated ducts can occur more than 50% of the time in many areas of the world at altitudes from near zero to several km.

Surface-based ducts from elevated trapping layers are formed by the same meteorological mechanisms as elevated ducts, but their trapping effects extend to the surface. A surface-based duct will exist when the M-value at the top of the trapping layer is less than the M-value at the surface. As with elevated ducts, this mechanism is not strongly dependent on frequency and can result in tremendously extended radar and communications ranges at all frequencies above VHF for systems operating near the earth's surface. Surface-based ducts also can result in greatly increased levels of land or sea clutter from ranges normally well beyond the horizon. Such ducts occur annually 8% of the time worldwide, varying geographically from 1% in the North Atlantic to 46% in the Persian Gulf. The worldwide average thickness is 85 m, but thicknesses up to a few hundred meters are common. An interesting feature of surface-based ducts is a skip zone near the normal horizon, in which the duct has no influence. This skip zone is easily illustrated using a raytrace program such as RAYS, and a model to account for its effects is included in PROPR.

The third type of duct is the evaporation duct. Evaporation ducts are created by the extremely rapid decrease of moisture immediately adjacent to the sea surface. For continuity reasons, the air adjacent to the sea surface is saturated with water vapor, and the relative humidity is thus 100%. This high relative humidity decreases rapidly in the first few meters to an ambient value that depends on various meteorological conditions. The decreasing humidity creates a trapping gradient adjacent to the sea surface that gradually weakens with increasing height until a height is reached where M is minimized and dM/dh is zero. This height is known as the evaporation duct height and is a measure of the strength of the evaporation duct. Evaporation duct heights vary between 0 and 40 m, with a worldwide average of 13 m. For many cases, M is given by $M(h) = M(0) + 0.125\,h - 0.125\,d\,ln(h/h0)$, where h is height in m, d is duct height in m, and $h0 = 0.00015$ m. As opposed to surface-based ducts, this duct is quite sensitive to frequency in terms of its effects, with frequencies below about 2 GHz being only slightly affected. For frequencies above 2 GHz and terminal heights near the surface, the evaporation duct can result in substantially enhanced signal levels at ranges well beyond the horizon. Also, for short-range near-horizon paths and frequencies above 2 GHz, the evaporation duct is usually the dominant propagation mechanism.

The long-term statistical occurrence of surface-based ducts and their average thickness and the frequency distribution of evaporation duct height are readily available through the SDS program for most areas of the world. Individual elevated or surface-based ducts must be determined by measurements of the vertical distribution of refractivity. These measurements are usually made using balloonborne radiosondes, although airborne refractometers, rocketsondes, dropsondes, and instrumented aircraft of many types can be used. The evaporation duct height cannot normally be measured using these instruments, however, because of the much smaller-scale features of importance and uncertainties of spatial and temporal variations. Fortunately, techniques have been developed by Jeske [2] and Paulus [3] that allow the evaporation duct height to be readily determined by simple measurements of seawater temperature, and near-surface air temperature, humidity, and wind speed.

PROPR displays its results in one of three quantities: path loss, propagation factor, and radar signal-to-noise ratio. All are expressed in dB. Path loss is defined as the ratio of transmitted to received power between two loss-free isotropic antennas. EREPS uses free-space path loss as a reference in some displays, which is given by $32.44 + 20\log_{10}(FMHz) + 20\log_{10}(Rkm)$, where FMHz is the frequency in MHz and Rkm is the range in km. Note that path loss refers only to the one-way path between a transmitter and receiver, even though it can be readily used to determine radar performance, as will be explained later. Also note that path loss requires the use of isotropic antennas. If a directional antenna is used at either end of a path, it would be more proper to use transmission loss, which is defined as the ratio of the power radiated from the transmitting antenna to the resultant power that would be available from the receiving antenna if there were no circuit losses other than those associated with radiation resistance. For most practical applications, path loss and transmission loss are equal, provided the antennas are directed at the horizon and do not have an extremely narrow beamwidth. Propagation factor is defined as the ratio of the actual field strength at a point in space to the field strength that would exist at the same range under free-space conditions. Propagation factor is a desirable quantity, since it is an identifiable parameter in most radar-detection-range equations. Radar signal-to-noise ratio is the ratio of received power from the target to the thermal noise in the radar receiver. In this case, the two-way losses are taken into account.

For an illustration of some basic propagation effects, refer to the default PROPR display, which can be generated by executing PROPR at the DOS prompt, pressing Enter at the EREPS title page, and then pressing F10. The default PROPR display of path loss in dB vs. range should be displayed for a preset case of 5600 MHz, horizontal polarization, a transmitter height of 100 ft, and a receiver height of 30 ft. If this case is not displayed, the initialization file PROPR.INI should first be deleted as described in section 3.1. To exit any EREPS program, press Esc to go to the beginning of the program, then Esc a second time to quit. The environment in this case is a standard atmosphere with 10 knots of wind at the sea surface. The solid curve shows the path loss that would be expected as the range separation between the two terminals varies. The curved dashed line is a reference line that shows the path-loss variation for free-space conditions (i.e., no influence of earth or atmosphere), which is governed simply by geometrical spreading of the wave as it propagates away from the source. The straight dashed line is another reference line, corresponding to the path loss that would be expected in free space at a range of 100 nmi.

The default PROPR display shows three modes of propagation: optical interference, diffraction, and tropospheric scatter. The optical interference region corresponds to the shorter ranges up to about 10 nmi and is characterized by path-loss values that oscillate above and below the free-space level. This behavior is the result of the coherent interference of the direct and sea-reflected waves. Perfect cancellation does not usually occur, since the reflected path is weakened by the effects of wind-driven sea roughness and spreading due to reflection from a spherical surface. This display shows only two interference nulls, but many more can occur at shorter ranges than that shown. At ranges from roughly 10 to 30 nmi, the path loss increases much faster than the free-space reference as a result of diffraction. Diffraction is the process that allows a wave to propagate around a solid object, in this case the earth's curved surface. At ranges beyond 30 nmi, the path loss declines at a lesser rate due to a process known as tropospheric scatter, or simply troposcatter. This process is a result of scattering from multiple patches of refractive inhomogeneities. Troposcatter is not usually an important mechanism to consider for radar applications because of the relatively high path-loss values, but may be the dominant propagation mechanism for communications or electronic support measures (ESM) systems.

PROPR can be used to determine maximum detection, communication, or intercept ranges through the use of the thresholds. For example, the default display indicates that if communications can be established between a transmitter and receiver at 100 nmi in free space, then, under standard conditions, communication would be possible out to 18 nmi for transmitter and receiver heights as indicated. The same logic and threshold can be used to compute maximum radar detection range. To see how the environment can affect maximum range, press F5 (function key 5), use the arrow keys to position the flashing cursor at the evaporation duct height (EVD HT) entry, enter a value of 10, and press F9 to overlay a revised path-loss plot corresponding to a 10-m evaporation duct height. For this case, the maximum range is extended from 18 nmi to 27 nmi. Change EVD HT back to 0 and SBD HT (surface-based duct height) to 100 and press F9 again to see the effects of a 100-m-thick surface-based duct. In this case, note there is a hole or region of noncommunication or nondetection from 18 to 24 nmi due to the skip zone described earlier, but the maximum range occurs beyond 50 nmi. The other environmental parameters that can be changed are the effective earth radius factor K that affects the location of nulls in the interference region, the surface refractivity NSUBS that affects the troposcatter loss, the absolute humidity ABS HUM that determines absorption by water vapor molecules, and the surface wind speed WIND SP that affects the depths of the nulls in the interference region.

PROPR shows path loss or maximum range for one or more environmental conditions. To estimate the frequency of occurrence of those conditions, the SDS program should be used. As an example, the world average annual summary can be displayed by executing SDS at the DOS prompt, pressing Enter at the title page, and pressing F10 when the world map is displayed. There may be a delay while the world map is drawn if SDS has never before been run on your system. See section 3.1 for details. This summary shows the annual frequency of occurrence of evaporation duct height in 2-m increments, both numerically and with a bar chart, based on the average of all 292 of the 10- by 10-deg squares that were outlined on the world map. Other surface observation data that are listed numerically are the average evaporation duct height, here 13.1 m, and the average surface wind speed, here 16.9 knots. The lower right-hand section of the summary shows upper-air observation data derived from radiosonde measurements. In this case, the average of the 381 coastal, island, and station ship radiosonde stations in the SDS database shows an 8.0% occurrence of surface-based ducts with an average thickness of 85 m. The average surface refractivity is 339 and average earth radius factor is 1.45. Other options in SDS allow data from one or more squares and one or more radiosonde stations to be used as the basis for the summary. This program is intended to be the primary source of environmental data used in the PROPR program and is the basis for assessing statistical performance using EREPS.

3.0 OPERATION

3.1 SETUP

EREPS Revision 1.00 is supplied on two 5.25-in., 360-Kbyte disks. Disk 1 contains PROPR.EXE, RAYS.EXE, and BRUN30.EXE. Disk 2 contains SDS.EXE, MSDIST.DAT, MSINDEX.DAT, RS.DAT, WLDMAP.ASC, MANUAL.DOC, and REGISTER.DOC. BRUN30.EXE must be in the current directory or in the MSDOS path in order to run any of the EREPS programs. The other *.EXE files are the QuickBASIC 3.0 compiled executable files. MANUAL.DOC is the ASCII file containing this manual, and REGISTER.DOC is the ASCII file containing the EREPS registration form. The other files listed are data files required by SDS. As with any newly received software, it is a good idea to make backup copies of the distribution disks. If you received your copy of EREPS from another user, your disks may contain other files generated by the EREPS programs. There may be *.INI files or *.MAP files in addition to user data files that are not needed or desirable when setting EREPS up on a new system. Therefore, it is recommended that all such files in excess of those listed for the distribution disks be deleted before proceeding with setup on your system.

For hard disk users, it is recommended that a new directory named EREPS be created and all files from the distribution disks be copied onto it. Three subdirectories should be created in which user data files from each program will be stored. These can be named anything convenient to the user, but PROPR, RAYS, and SDS are often used. The user should then type in the full path name of each of these subdirectories at the bottom of the EREPS title page for each program the first time it is run. Each program will automatically create a *.INI file in the EREPS directory that includes the subdirectory path name, as well as user-selected color definitions and start-up default height and range units. Subsequent use of the programs will read the *.INI file and place the path name at the prompt on the title page, so a user need only press Enter or F1.

For 3.5-in., 720-Kbyte floppy users, all distribution files can be copied onto one floppy. Create subdirectories as described above. For CGA systems, such as most portable PCs, there will be enough space for the CGA.MAP file created by SDS. For EGA users, the *.DOC files will have to be removed to make space for the map files. A CGA user may also wish to remove the *.DOC files to make room for more user data files.

To run EREPS from a 5.25-in., 360-Kbyte drive, a working disk for SDS must be made containing the following files: SDS.EXE, BRUN30.EXE, MSDIST.DAT, MSINDEX.DAT, RS.DAT, and WLDMAP.ASC. Distribution disk 1 contains all files needed to run PROPR and RAYS. Subdirectories should be made on each working disk as described above for the appropriate program.

Every time SDS is run, it checks the hardware configuration to determine the type of graphics adapter in use and then checks to see if the appropriate map file exists in the current directory. If it does not exist, SDS will draw the map from other data files and then save the new map file for subsequent use. Therefore, expect some delay the first time SDS is run as a new installation.

Most users will want the capability to dump the EREPS graphics displays to a printer. The EREPS software supplied does not provide for this capability. There are many graphics dump programs available. For CGA users, the GRAPHICS command supplied by

IBM and some other vendors will work with Epson-compatible printers. A very good graphics dump program that works with both CGA and EGA adapters and a wide variety of printers is GrafPlus, available from Jewell Technologies, Inc. (206) 937-1081. Cost is about $50. Most dump programs are memory-resident, and once loaded into memory are activated by the Shift-PrtSc keys.

You may fill out the EREPS registration form provided in the ASCII file REGISTER.DOC and mail it to the address indicated to ensure receipt of the next upgrade to EREPS. Please limit registrations to one per physical location or working group. You may copy the EREPS distribution disks freely and provide them to co-workers.

3.2 COMMON FEATURES

Each EREPS program begins with a title page, showing the program title, revision number, date, point of contact, and a brief description of what the program does. Reminders of a few important keys are given, and the program prompts the user to supply the desired full path name for storage of user data files. A default path name is indicated by the program from the *.INI file, if one exists. Otherwise the current path name is indicated. If the indicated path is acceptable, press F1 (function key 1) or the Enter key to proceed. If the path is unacceptable, type the desired full path name, then press F1 or Enter. A *.INI file will be created containing this new path name. It is recommended that separate paths (directories) be maintained for each of the EREPS programs, but it is not required.

The escape key (Esc) is a very important key to remember in all EREPS programs. Esc has two functions. If it is pressed from anywhere in the program other than at the logical start of the program, then program flow is transferred to the logical starting point. At this point only, pressing Esc will cause the program to quit, and control is transferred back to MSDOS. Thus from any level in the program, pressing Esc once will go to the logical start of the program, and once again will exit the program. The logical starting point for both PROPR and RAYS is the initialization mode (INIT). In this mode, the user selects a type of display or method of data entry and sets values for units (e.g., nmi or km) and other parameters that control the physical appearance of the display. Height and range units selected here will always be used at program start-up if the user presses F4, which will create or update the *.INI file accordingly. Most of the parameters set in INIT can later be changed under the OPTIONS mode. The OPTIONS mode also allows the user to redefine the color selections if an EGA graphics adapter is being used. SDS does not have an INIT mode, since there are no choices on the physical appearance of the displays. Thus the logical starting point for SDS is its MAP mode, described later.

EREPS program flow is primarily controlled by the function keys. Each function key currently available is indicated on the bottom line of the display. The function key labels can be turned off or on by pressing F1:KEYS. Turning the labels off is useful for dumping a "clean" graphics image of the current screen to a printer for use in reports or viewgraphs. F2:HELP results in a list of key definitions on the lower half of the screen. This list begins at the section most appropriate to the current position within the program. The user may scroll up or down through the list using the up or down arrow keys. Pressing F2 while in the HELP mode will reinstate the lower half of the screen to its previous appearance.

F6:LABEL is a useful function that allows the user to enter custom labels or to modify EREPS legends by typing any character at normal row/column positions anywhere on the screen except the very bottom line, which is reserved for function key labels only. The position of the cursor will be displayed in the bottom right-hand corner of the screen. Use arrow keys to move cursor position on the screen. The Home key will place cursor in the center of the screen. The Del key and space bar will both erase the current character. The backspace key will erase the character to the left and place the cursor there. The tab key will move the cursor to the next tab position (11, 21, etc.). The Enter key will place the cursor at the left side of the screen and down one line. PgUp and PgDn keys will place the cursor at the top and bottom of the screen.

Some of the displays in PROPR and RAYS have one or more alternate formats for displaying parameter values. The PgUp or PgDn keys are used to select these alternate formats. If no alternate format is available, pressing these keys will result in a beep. Note that pressing any key which has no current meaning to the program will result in a beep.

PROPR and RAYS incorporate a flexible data entry and editing capability. Editing is accomplished on the same display as the most recently generated plot, thus giving maximum feedback to the user. In general, the user simply uses the arrow keys to position the flashing cursor on the field he wishes to enter or change and types in the value desired. A long prompt explaining the data item and its limits is given for each data field. Both numeric values and units for any item can be changed at any time during the entry or edit operations. To change units, the left arrow key is used to position the cursor on the units field. A list of keys and their functions during entry or edit operations follows:

Left arrow key - Moves cursor one character position to the left. If cursor is in leftmost position of a field, then cursor will move to the next field to the left or above.

Right arrow key - Moves cursor one character position to the right. If cursor is in the rightmost position of a field, then cursor will move to the next field to the right or below.

Up arrow key – Moves cursor to next field above.

Down arrow key – Moves cursor to next field below.

Tab key – Moves cursor to next field to right or below.

Shift tab key – Moves cursor to next field to left or above.

Enter key – Accepts current value if within bounds and moves cursor to next field to right or below. If value is outside of bounds, then program beeps and prints an error message.

Ctrl Enter – Same as Enter, except no test on bounds is made.

Backspace key – Moves cursor one space left and enters a blank character.

Home key – Moves cursor to first field on page.

End key – Moves cursor to last field on page.

PgUp/PgDn keys – Changes to alternate format display.

Space bar – For numeric or string data, enters a blank. For entries with limited choices, scrolls to next choice.

Ctrl c – Clears the current field.

PROPR and RAYS both utilize the F10:PLOT and F9:OVERLAY functions. PLOT erases the currently displayed plot, if any, and produces a new plot based on the currently defined parameters. This is the normal function to use after entering or editing data values to see results. If the user wishes to compare the currently defined case with one or more previous cases, he should use the OVERLAY function. OVERLAY does not erase the existing plot before plotting the new one. This function is particularly useful for displaying the effects of changes in one parameter, such as evaporation duct height, over a range of expected values.

PROPR and RAYS incorporate a XHAIR (crosshair) mode. This mode will display a crosshair in the center of the screen or at the crosshair's last position during the last call to XHAIR. The abscissa and ordinate values at the center of the crosshair appear in the lower-right corner of the screen. Pressing any of the arrow keys will move the crosshair in the direction of the arrow. If the crosshair is moved beyond a boundary, it will wrap around to the opposite side. The Home key will place the crosshair in the center of the plot. The End key will place the crosshair at the rightmost side of the plot. The Enter key will place the crosshair at the leftmost side of the plot. The PgUp and PgDn keys will place the crosshair at the top and bottom of the plot. Within the XHAIR mode, F4:COARSER and F5:FINER can be used to adjust the step size of the cursor. F6:MARK will place a small box mark on the plot centered on the cursor.

All EREPS programs allow the user to save (write) user data to files or to get (read) the data from these files back into the program for subsequent use. The directory used is the one specified by the path name at the title page prompt. Following is a list of keys and their functions for file mode operations.

F4:LIST DIR - Lists the files on the current directory.

F5:NEW DIR - Prompts for a new directory. The full path name (e.g., C:\EREPS\MYFILES) must be given. If directory does not exist, it will be created.

F6:GET FILE - Prompts for a file name, then reads in all data from that file. Only valid MSDOS file names and extensions are allowed. Exits from file mode automatically.

F7:SAVE FILE - Prompts for file name, then writes all current data to that file. Only valid MSDOS file names and extensions are allowed. Exits from file mode automatically.

F8:DELETE FILE - Prompts for file name, then deletes file.

PROPR and RAYS use the F3:EXIT function to transfer program flow from the current mode to the previous mode. For instance, if the user selects XHAIR mode from EDIT mode and then presses F3:EXIT, the program will return to the EDIT mode.

Following is a summary of the most important modes and keys used by PROPR and RAYS.

DISPLAY - Displays plot & data. Allows access to other modes
Esc:INIT - Select display type, units, & related parameters
F1:KEYS - Turns key labels off/on
F2:HELP - Shows key definitions
F3:ENTRY - Allows data entry for most parameters
F4:FILE - Enters user-data file mode
    F4:LIST DIR - List contents of current directory
    F5:NEW DIR - Select a new directory
    F6:GET FILE - Reads all parameters from designated file

F7:SAVE FILE – Writes all parameters to designated file
F8:DELETE FILE – Removes designated file
F5:EDIT – Allows most parameters to be changed
F5:OPTIONS – Allows most INIT parameters to be changed
F4:COLORS – Allows color definitions to be changed
F3:EXIT W/O CHANGE – Ignore selected definitions
F4:CHANGE THIS SESSION – Use selections this time only
F5:CHANGE PERMANENT – Write selections to *.INI
F6:LABEL – Allows typing on display
F7:XHAIR – Allows numeric readout using crosshair
F4:COARSER – Sets larger step size
F5:FINER – Sets smaller step size
F6:MARK – Places a box mark at current crosshair position
F9:OVERLAY – Generates plot over existing plot(s)
F10:PLOT – Erases display, generates new plot

3.3 PROPR

In the INIT mode of PROPR, the user must choose one of the four types of display: (1) Path loss vs. range with up to four user-defined thresholds; (2) Path loss vs. range with one threshold based on ESM parameters; (3) Path loss vs. range with one threshold based on radar parameters; or (4) Radar signal-to-noise ratio vs. range. For display types 1 to 3, the user is prompted for ordinate type: path loss or propagation factor. Then the default units for height and range are selected. These units will be used throughout the program (except for EVD HT and SBD HT that always default to meters) unless changed by the user in ENTRY or EDIT modes. Maximum plot range is next entered. If a value of zero is selected, the program will compute a maximum plot range based on terminal heights. The number of nulls desired in the optical region is specified as at least 2. The user needs to pay attention to the combination of number of nulls and maximum plot range, for in some cases the range of the closest null will be greater than the maximum plot range, in which case the user will see no results at all. The clutter type (average or bounds) and the radar calculations (simple, integration, or visibility factor) are selected depending on the type of display selected. In the ENTRY and/or EDIT modes, the values for frequency, polarization, transmitter and receiver heights, environmental parameters, free-space range, and ESM or radar parameters are entered or changed. For display types 3 and 4, there is an alternate format display that shows all radar parameters as well as environmental parameters. Pressing F10:PLOT or F9:OVERLAY generates the desired display.

3.4 RAYS

In the INIT mode of RAYS, a choice must be made for one of four methods of environmental data entry: 1 – Numerical height-refractivity levels; 2 – Graphical height-refractivity levels; 3 – Refractivity-profile characteristics; or 4 – Pressure, temperature, and humidity. After the desired method is chosen, the user selects the height and range units that will be used for the rest of the current session, unless changed for individual parameters by the user in ENTRY or EDIT modes. The angle units are next selected as either milliradians or degrees. The default is milliradians. Refractivity units are selected as either M-units or N-units, with the default being M. Ray smoothness factor is set as a number between 0.1 and 10, with the default of 3. Smaller numbers result in smoother rays, but longer calculation time. The ray smoothness factor is the angular increment in milliradians between points calculated along each ray. Maximum plot height and range are chosen, with the defaults being 20,000 and 200. Units are as specified above, but can be changed independently at each prompt by means of the left arrow key. For PCs equipped with an EGA with more than 64 Kbytes of memory, RAYS allows an optional altitude error display. A prompt is given to set this option to yes (Y) or no (N). The option is preset to N/A for computer configurations other than that stated above. If the altitude error display is not chosen, then a prompt is given to display reflected rays. A response of Y will display reflected rays, and N will not. The default is set at Y. If the altitude error display is chosen, then a prompt is given to set the altitude error increment from 1 to 2000 ft or 1 to 1000 m. Default is 500. This increment defines each color on the 10-color scale for the display. Reflected rays are not allowed for the altitude error display. The final parameter set in INIT is the option to self-scale angles to the maximum altitude and range values of the plot. Y will self-scale and N will not. Default is set to Y.

In ENTRY and/or EDIT modes the values for antenna height, number of rays to be plotted, minimum, and maximum angles can be entered or changed. In ENTRY mode the environmental profile is entered according to the input method chosen in the INIT mode.

For method 1 the environmental profile is entered in height and refractivity levels numerically. For method 2 the profile is entered in height and refractivity levels graphically, that is, a graph will be displayed of height vs. refractivity and the user then moves the cursor to the desired position and selects the height/refractivity level. For method 3, there are three features the user can specify. The first is a duct, for which the duct top, bottom, and trapping layer thickness are specified. The second and third features are the top and bottom of a layer. for which the gradient is to be specified. If no features are specified then the program uses a standard gradient to perform the ray trace. Entering a profile using method 4 is similar to that for method 1. Pressure, temperature, and humidity are entered numerically for each level. There are two added parameters the user must enter for this method: (1) radiosonde launch height - must be between 0 and 30,000 ft or 0 and 10,000 m. Default is set at 0. (2) temperature units - Celsius (C) or Fahrenheit (F). Default is set at C. For all input methods, a refractivity gradient of 118 M/km is assumed at altitudes above those entered by the user.

For methods 1 through 4 there are two alternate format displays the user can work with in EDIT mode. The first is the profile displayed numerically in height and refractivity levels, and the second is the profile displayed graphically. In the graphical display, a dashed line indicates the standard gradient assumed above user-entered data. For methods 3 and 4 there is a third alternate format display, which is the profile displayed according to the initial input method used.

If the altitude error display is chosen, then in the main display mode an extra function key will be defined — F8:LEGEND. This function produces an altitude-error color-bar legend that can be relocated to the most convenient location on the screen. Use the arrow keys to move a cursor to the desired location, then press F4 to relocate the legend.

3.5 SDS

After the title page, SDS goes to the MAP mode. In the MAP mode, a world map of Marsden Squares (10 deg latitude by 10 deg longitude) is displayed and the user selects the Marsden Square or combination of squares for which a summary is desired. An individual square is selected by placing the cross in the desired square, using the arrow keys, and then pressing Enter or F10:SUMMARY. A group of squares can be selected by repeatedly placing the cross on individual squares and pressing F4:SELECT, which places a selection mark in the current square. Squares previously selected can be removed using F5:REMOVE. When all squares desired are marked, use Enter or F10:SUMMARY to produce the averaged summary. The world average of all 292 squares shown on the map can be obtained by placing the cross in the world average box on the map prior to pressing Enter or F10. In the MAP mode, F6:GET FILE can also be used to read in a file with a predefined combination of selected squares.

In the SUMMARY mode, the user may save the current defined area and summary data for future use by pressing F7:SAVE FILE. A prompt will be given to provide a file name. If a summary was produced for a single square, and there are multiple radiosonde stations within that square, the summary will normally show the averaged upper-air data over those stations. A single station can be chosen by pressing F5:CHOOSE UPPER AIR, which will then present a selection of stations. Move the * marker with the up or down arrow keys to the desired station, then press Enter or F10:SUMMARY to produce the single-station summary. In SUMMARY mode, press F10:MAP to return to the map mode to select a new square or area.

4.0 PROPAGATION MODELS

The propagation models in PROPR are similar to those used in the loss product of IREPS. No attempt is given here to fully describe these models. Rather, a brief discussion is presented to give the user a feeling for the level of complexity and their usefulness. A lot of effort has gone into making the models run quickly in a PC environment so multiple overlays can be quickly generated to assess parameter sensitivities. The models in many ways are an improvement to IREPS, especially at low altitudes and near the horizon. The models are not as accurate as full waveguide or parabolic equation models that have been developed in recent years, but these generally will not run in an interactive mode on a PC. For the case of troposcatter, PROPR will give better assessments than the more sophisticated models that universally ignore this sometimes important mechanism.

In the optical region, refractive effects are taken into account only through the use of the effective earth radius factor following the methods described by Kerr [4]. Path-length difference between the direct and sea-reflected rays is computed by Kerr's methods out to the greater of two ranges: the one at which the path-length difference equals one-quarter wavelength, or at which the grazing angle equals a limit determined by Reed and Russell [5] at which the spherical-earth divergence factor calculation becomes invalid. Polarization-sensitive reflection coefficients from the sea follow Reed and Russell, but are modified for wind-driven sea roughness following models of Ament [6], Beard [7], and Barrick [8]. The optical region models are not affected by the evaporation duct height, surface-based duct height, or surface refractivity, even though there may be some real effects from these factors.

If the evaporation duct height is zero, then diffraction is calculated by the methods outlined by Blake [9], except that the minimum range at which calculations are valid was taken from Reed and Russell. If the evaporation duct height is not zero, then the least loss from diffraction or a model derived from the Naval Ocean System Center (NOSC) waveguide program is used. The NOSC model is based on easy-to-compute algorithms that have been fitted to the waveguide results for a family of evaporation duct profiles at several frequencies. The evaporation duct model also shortens the optical maximum range to a value no less than that corresponding to the last optical peak. This model works reasonably well provided that one waveguide mode dominates the total solution. In practice this method gives good results unless the combination of duct height and frequency gets too high. Limits will be given in a later section. Also the diffraction and evaporation duct model are based on $k = 4/3$, even though the user may have selected a different value of k for investigating optical region behavior. None of the beyond-horizon models are sensitive to polarization effects.

Between the greatest range at which optical region calculations can be made and the shortest ranges at which diffraction or evaporation duct calculations are valid, an interpolation technique originally described by Kerr is used. This technique uses linear interpolation on the logarithm of the propagation factor. In other words, the logarithm of the propagation factor is calculated at the optical maximum and the diffraction minimum. Then linear interpolation on range is used to determine the logarithm of the propagation factor at intermediate ranges.

The troposcatter model is taken from Yeh [10] but has been modified by adding the "frequency gain" factor from Rice et al. [11] that gives much better values for low-altitude paths. No aperture-to-medium coupling loss has been included in the model, since PROPR assumes isotropic antennas. Troposcatter is calculated and added at all ranges beyond the minimum diffraction range until the troposcatter loss is 18 dB less than the diffraction or evaporation duct loss. At ranges beyond this point, only troposcatter is calculated. The troposcatter model is sensitive to k and surface refractivity. The troposcatter model can be effectively suppressed in PROPR by setting NSUBS to 0 if comparisons are desired with other models that do not account for troposcatter. For realistic assessments NSUBS should be set to a reasonable surface refractivity value.

The surface-based duct model assumes a certain shape to the M-vs.-height profile. The assumption is that the upper 10% of the duct is a trapping layer and that the difference in modified refractivity between the top of the duct and the surface is zero. Below the trapping layer the refractivity gradient is determined by k. The model calculates the limiting ray path between the transmitter and receiver heights, and the resulting range is set as the minimum range at which full trapping by the duct exists (i.e., the far end of the skip zone). At lesser ranges, an increase of loss is set as 1 dB/km for all frequencies, based on measured data. At greater ranges, the model is the same as is used in IREPS, which is a frequency-dependent curve fitted to measured data. The surface-based duct model is used whenever its computed loss is less than the loss of all the other models except absorption. This model should be considered only as an approximation, best suited to illustrate the skip zone behavior and to indicate approximate range extensions that can result from this mechanism.

The loss attributable to water vapor absorption is added to all other losses computed by PROPR. The model is taken directly from CCIR Recommendations [12] and is dependent on the absolute humidity parameter ABS HUM, given in grams/cubic meter. A temperature of 15°C is assumed. For frequencies below about 10 GHz, this attenuation is negligible, but at the highest valid PROPR frequency of 20 GHz, the contribution can be quite noticeable, in particular at long ranges. No model is included for oxygen absorption, since the attenuation is negligible at all frequencies less than 20 GHz.

PROPR contains a model for sea clutter taken from Horst, et al. [13] of the Georgia Institute of Technology (GIT). This model is sensitive to surface wind speed and direction, but does not take into account any ducting effects. The GIT model is thought to be good within ± 5 dB for standard propagation conditions only. PROPR has the option of showing either the average or the 5-dB bounds above and below the average GIT values. Calculations of sea clutter are not made for grazing angles less than 0.1 deg in this model.

The models of the raytrace program RAYS are based on small-angle approximations to Snell's law and the assumption of a linear variation of modified refractivity with height in up to 14 vertical segments. Analytical expressions are used to describe the ray path in each vertical segment based on the following equations. $A1^2 = A0^2 + 2 \times 10^{-6}\, dM$, where A1 is the elevation angle (from the horizontal) in radians at the top of a vertical segment, A0 is the elevation angle at the bottom of the segment, and dM is the modified refractivity difference between the top and the bottom of the segment. Then $dR = (A1 - A0)/(10^{-6}\, dMdh)$, where dR is the ground range increment across the ray segment, dMdh is the M-gradient with height, and the units of range and height are the same. All of the calculations of ray trajectories are based on the previous two equations, using care to take direction into account with the proper sign of the M-value changes. For reflections from the surface, it is assumed that the reflected and incident elevation angles are equal. Although SDS was designed for radio-wave applications, the algorithms apply equally well to optical wavelengths, provided appropriate N- or M-unit values are entered by the user over the entire height interval of interest. Altitude error is computed as the absolute value of the difference between a ray's height and the height at which a ray with the same elevation angle would be at the same range under standard conditions (i.e., a single gradient of 118 M/km). Superrefractive and trapping gradients usually produce altitude errors such that apparent altitude is greater than the actual altitude. The models that relate pressure, temperature, and relative humidity to radio refractivity and altitude are taken from Berry [14] and Bean and Dutton [15].

5.0 RADAR CALCULATIONS

PROPR contains the ability to convert radar system parameters such as frequency, pulse length, etc. to free-space range for further use within the program. The models to do this conversion are taken from Blake [9]. Three types of radar calculations are allowed by the program: "simple," "integration," and "visibility factor." A simple type calculation is normally used for a rotating pulsed radar that uses noncoherent pulse integration to increase its sensitivity. The number of pulses integrated in the simple case is calculated from horizontal beamwidth, pulse repetition frequency, and rotation rate. For integration type calculations, the user must supply the number of pulses integrated and specify whether coherent or incoherent integration is used. The signal-to-noise ratio required for a given probability of detection and false alarm is known as either the visibility factor or detectability factor, D0. For incoherent integration, Blake's equation 2.29 is used to calculate D0 for a uniform-weight integrator and a square-law detector. For coherent integration, Blake's equation 2.21 is used to calculate D0 based on D0 for a single pulse derived from equation 2.29. If the radar calculation type is set to "visibility factor," then the user must supply his own value of visibility factor that is used in place of the D0 calculations described above. This option may be the most useful to users dealing with modern sophisticated radar systems that use complicated signal processing schemes. Blake's equation 1.34 is used to calculate the radar free-space detection range based on peak power transmitted, radar antenna gain, target cross section, frequency, system noise (Ts), D0, and system losses (L). The bandwidth correction factor, Cb, in equation 1.34 was arbitrarily set to 1. Also Ts has been set to 290 NF, where NF is the receiver noise figure (as a ratio, not in dB). All other losses not specifically mentioned above must be accounted for in the system losses, such as transmission line loss, filter mismatch loss, signal processing loss, beam-shape loss, etc. If a fluctuating target is selected in PROPR, the fluctuation loss from equation 2.45 for a Swerling Case 1, kF = 1, chi-square target is included in the free-space range calculation and the corresponding target signal-to-noise ratio. The target signal-to-noise ratio is derived from target signal power calculated from Blake's equation 1.18. Compressed pulse length is used by PROPR only for the calculation of sea-clutter area, using Blake's equation 1.43 for a zero grazing angle.

BASIC program formulas to calculate the visibility factor, radar free-space range, and signal-to-noise follow:

antgn	= Transmitter antenna gain (dBi)
dbloss	= System losses – line, beamshape, etc. (dB)
fgnois	= Receiver noise figure (dB)
freq	= Frequency (MHz)
horzbw	= Horizontal beamwidth (deg)
horzsr	= Horizontal scan rate (rpm)
pkpwr	= Peak power (kW)
psubd	= Probability of detection
psubfa	= Probability of false alarm negative exponent, 2 to 12
hits	= Number of pulses integrated
prf	= Pulse repetition frequency (Hz)
sigma	= Target cross section (sqm)
tau	= Pulse width (microsec)
F	= Propagation factor E/E0
Rkm	= Range in km

```
     t = 1.8 * psubd - 0.9
     gd = 1.231 * t / sqr(1.0 - t*t)
     gfa = 2.36 * sqr(psubfa) - 1.02
     xnot = (gfa + gd) ^ 2

--- For "simple" calculations, compute hits --
     hits = (horzbw * prf) / ( 6.0 * horzsr)
     if hits < 1.0 then hits = 1.0

--- For incoherent integration, visibility factor D0 is ---
     D0 = xnot/(4.0*hits) * ( 1.0 + sqr(1.0+16.0*hits/xnot) )

--- For coherent integration, visibility factor D0 is ---
     D0 = xnot/(4.0*hits) * ( 1.0 + sqr(1.0+16.0/xnot) )

--- Fluctuation loss factor ---
     Fl = 1                                        ' steady
     Fl = 1 / ( -log(psubd) * (1.0 + gd/gfa) )     ' fluctuating

--- Free-space range in km ---
     dBterm = 10.0 ^ ( 0.1 * (2.0*antgn - fgnois - dbloss) )
     Rkmnum = dBterm * pkpwr * sigma * tau
     Rkmden = freq * freq * D0 * Fl
     Fsrkm  = 58.0 * (Rkmnum/Rkmden) ^ 0.25


--- Free-space path loss in dB ---
     FsldB = 32.44 + 8.686*log(Fsrkm) + 8.686*log(freq)

--- Calculate noise power in dBW ---
     pndb = 4.343 * log(4.0E-15 / tau) + fgnois

--- Target power in dBW ---
     prnum = pkpwr * sigma * F^4
     prden = freq * freq * Rkm^4 * Fl
     prdb = -73.4 + 4.343*log(prnum/prden) + 2*antgn - dbloss

--- Signal-to-noise in dB ---
     sndb = prdb - pndb
```

6.0 ESM CALCULATIONS

The path-loss threshold for ESM systems is calculated as the decibel difference between the effective radiated power and the ESM receiver sensitivity, as adjusted by appropriate system losses. For peak power P in kW, transmitter antenna gain G in dBi, ESM system sensitivity S in dBm, and system losses L in dB, the path-loss threshold T in dB is calculated as

$$T = 10\log_{10}(P) + 60 + G - S - L.$$

For example, if $P = 100$ kW, $G = 30$ dBi, $S = -80$ dBm, and $L = 5$ dB, then $T = 185$ dB. Normally, ESM system sensitivity includes receiving antenna gain and line losses. Thus L would be used to account for the emitter's transmission line losses and other losses associated with the transmitter. Under PROPR display option 2, the threshold loss T is plotted on the path-loss display as a dashed line. Path losses less than the threshold correspond to intercept capability.

The same display option and system parameters can be used to assess communications systems. The only difference is that system sensitivity should be adjusted to account for the signal-to-noise-ratio margin associated with a given level of communications quality.

7.0 LIMITATIONS

The limitations of the EREPS programs are as follows:

1. Frequency: 100 MHz to 20 GHz in PROPR.

2. Over-water paths: With the single exception of troposcatter, the PROPR models apply only to over-water paths. PROPR is not valid for terrestrial paths.

3. Horizontal homogeneity: Neither PROPR or RAYS takes into account any horizontal change of environmental parameters. It is believed this limitation is justified at least 85% of the time, as described by Hitney, et al. [16].

4. Antenna heights: Although antenna heights are accepted by PROPR from 3 to 30,000 ft (1 to 10000 m), the program may be in error for some combinations that result in large angles. PROPR will give the best results for one terminal low, say up to 300 ft, and the other up to the maximum altitude. RAYS should give acceptable results for all allowed inputs.

5. Effective earth radius factor: The diffraction and evaporation duct models are not dependent on k. Variations in k should only be used to study changes in the optical region nulls. Otherwise k should be kept at a value near 1.33.

6. Optical region: If large numbers of optical region nulls are requested from PROPR, the elevation angles may exceed the small-angle assumptions, causing null locations to be in error. No check is made by the program for these angles.

7. Evaporation duct height: PROPR uses a single-mode model of propagation for an evaporation duct and may be in error for duct heights greater than 30 m at 3 GHz, 22 m at 5 GHz, 14 m at 10 GHz, and 10 m at 18 GHz (interpolate between frequencies for other limits). Below 2 GHz PROPR should give acceptable results for all duct heights in the 0- to 40-m range allowed.

8. Surface-based duct model: This single-mode empirical model is approximate and is best used to illustrate the skip zone effect and range extensions. An exact vertical refractivity profile would have to be provided to a full-wave-solution program to get accurate results, which is beyond the scope of PROPR.

9. Sea clutter: The sea-clutter model in PROPR is limited to standard atmospheric conditions only, even though it can be shown on the same display with target returns that are enhanced by ducting.

8.0 APPLICATION EXAMPLE

This application example is included to illustrate how PROPR and SDS can be used together to assess statistical propagation performance. The example is based on a propagation experiment performed between the Greek islands of Naxos and Mykonos in 1972 and reported on by Richter and Hitney [17]. Transmitters at 1.0 GHz (L-band), 3.0 GHz (S-band), and 9.6 GHz (X-band) were located on Naxos at 4.8 m above mean sea level (msl). In addition, a transmitter at 18.0 GHz (Ku-band) was located at 4.5 m above msl. Three receiving antennas were positioned at Mykonos for each frequency, with the highest being at 19.2 m above msl for L-, S-, and X-bands and 17.8 m above msl for Ku-band. The range separation was 35.2 km, corresponding to a somewhat over-the-horizon propagation path. Horizontal polarization was used at all four frequencies. Path loss was measured for four 3-week periods in February, April, August, and November, except for Ku-band, which was measured only during August and November. All data were averaged over a 5-minute period and recorded every 15 minutes, 24 hours per day. These data have been reported in Reference 17 in several ways, one of which is frequency distributions of path loss for all measurement periods combined. These data will be presented later in this section for comparison to EREPS assessments.

The first step in using EREPS to assess propagation effects is to run the SDS program for the appropriate area. For the case described above (latitude 37N, longitude 25E), the correct SDS summary will show surface observation data from Marsden Square 142 and upper-air observations averaged over six stations within the square. The annual average evaporation duct height is shown to be 13.1 m, and the average surface wind speed is indicated as 12.3 knots. From the six averaged radiosonde stations it is seen that surface-based ducts would be expected about 11% of the time with an average thickness of 117 m. Also the average surface refractivity would be 334 N-units and the earth radius factor would be 1.49. The evaporation duct height distribution shown below as Table 1 indicates that evaporation ducting effects are quite strong.

Table 1. Evaporation duct height distribution for the Greek islands area, Marsden Square 142. From SDS program.

EVD HT, m	%	EVD HT, m	%	EVD HT, m	%
00-02	2.0	14-16	11.2	28-30	0.9
02-04	3.4	16-18	8.7	30-32	0.5
04-06	6.7	18-20	6.7	32-34	0.4
06-08	9.5	20-22	4.6	34-36	0.2
08-10	11.8	22-24	3.2	36-38	0.1
10-12	13.4	24-26	2.1	38-40	0.1
12-14	12.9	26-28	1.4	>40	0.2

The next step in this example is to use PROPR to investigate the sensitivity of path loss to environmental parameters. At L-band, for example, PROPR will indicate a path loss of 152.9 dB for standard atmospheric conditions for a transmitter height of 4.8 m and a receiver height of 19.2 m at a range of 35.2 km. The following parameters were selected to represent standard atmospheric conditions: EVD HT = 0; SBD HT = 0; K = 1.333; NSUBS = 334; ABS HUM = 7.5; and WIND SP = 12.3 knots Note the crosshair mode of PROPR can be readily used to read the path-loss values from the display, but that one user may read values that are slightly different than another due to display resolution. In any case, readings should be accurate to about 0.5 dB, which is better than the probable overall accuracy of the models. By varying one parameter at a time and using the overlay feature of PROPR, one can easily simulate various conditions and see the effects on path loss over the given path. For example, a 117-m-thick surface-based duct does not affect this path at all, because of the skip zone phenomenon. Therefore, one can conclude that surface-based ducts are not likely to affect the path loss in this case, even though such ducts will occur about 11% of the time in the Greek islands area. On the other hand, varying the evaporation duct height through the range of expected values shows that path loss will vary substantially, in particular at the higher frequencies. Table 2 shows the path loss from PROPR vs. evaporation duct height for the four frequencies and corresponding geometries.

Table 2 indicates duct heights beyond those recommended in item 7 of section 7 for use in PROPR. Comparing these duct heights with the duct height distributions of Table 1 indicates that EREPS can yield statistical assessments of path loss at L- and S-bands, but will be questionable at X- and Ku-bands. The most useful statistical presentation is often the accumulated frequency distribution of path loss, which can be quite easily determined from the previous two tables. For example, at L-band, path loss will always exceed 130 dB. Path loss greater than 140 dB occurs for duct heights less than 36 m, which from Table 1 is 99.6%. Path loss greater than 150 dB corresponds to duct heights less than 17 m, or 75.2%. The accumulated frequency distributions thus determined are presented in Table 3 for all four frequency bands. Also shown are the observed distributions derived from Reference 17.

Examination of Table 3 shows that L-, S-, and X-band calculations are in reasonably good agreement with the observations, but Ku-band calculations indicate substantially higher path-loss values than were observed. This disagreement is due to the frequent occurrence of duct heights in Marsden Square 142 that are beyond the recommended limits of EREPS at Ku-band. Note that X-band agrees quite well in spite of some duct heights occurring that are beyond the recommended limit. For applications in other areas where duct heights are predominantly low, such as in the North Atlantic Ocean, the EREPS assessments would prove to be good even at the highest frequencies.

Table 2. Path-loss values from PROPR vs. evaporation duct height for the Greek islands experiment frequency bands and geometries described. The * indicates duct heights beyond those recommended for use in PROPR.

EVD HT, m %	Path loss in dB from PROPR L	S	X	Ku
0	152.9	161.7	172.9	181.9
2	152.5	161.6	166.1	168.1
4	152.3	160.5	161.8	157.3
6	151.9	158.9	154.0	146.0
8	151.4	157.4	146.8	145.1
10	151.0	155.3	139.7	155.8
12	150.7	152.2	140.2	166.1*
14	150.4	148.4	143.5	172.6*
16	150.1	145.1	148.3*	172.6*
18	149.9	142 3	152.0*	172.6*
20	149.2	139.4	154.7*	172.6*
22	147.8	136.4	155.8*	172.6*
24	147.1	135.1	153.3*	172.6*
26	145.4	133.9	153.3*	172.6*
28	144.4	133.7	153.3*	172.6*
30	143.8	134.2	153.3*	172.6*
32	142.7	135.8*	153.3*	172.6*
34	141.2	137.0*	153.3*	172.6*
36	140.0	138.1*	153.3*	172.6*
38	139.0	139.1*	153.3*	172.6*
40	137.6	140.2*	153.3*	172.6*

Table 3. Percent of time path loss is exceeded for the Greek islands experiment as calculated by EREPS from annual duct height distributions and as observed for all seasons measured at each frequency band. Geometries as stated in text.

Path Loss, dB	Percent of time path loss is exceeded							
	L		S		X		Ku	
	EREPS	OBS	EREPS	OBS	EREPS	OBS	EREPS	OBS
120	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
130	100.0	95.8	100.0	80.6	100.0	94.3	100.0	100.0
140	99.6	89.5	84.6	65.3	83.6	74.1	100.0	98.9
150	75.2	64.5	40.1	39.3	41.6	38.5	81.3	70.5
150	0.0	9.5	8.8	3.9	7.1	4.7	64.5	27.3
170	0.0	0.0	0.0	0.0	1.0	0.9	48.8	7.1
180	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.8
190	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1

Table 3 illustrates the substantial reductions in path loss compared to diffraction levels attributable to the evaporation duct. For example, at X-band the diffraction path loss is 173 dB and the path loss exceeded 50% of the time is 148 dB, resulting in an improvement of 25 dB. In this case the free-space path loss is 143 dB, and the median observed (or calculated) path loss is much closer to free space than to diffraction.

The EREPS user should take note that methods similar to those used in this example can be applied to maximum detection, communication, or ESM ranges. Thc user would employ PROPR to determine maximum range vs. duct height and then use the duct height distributions from SDS to compute distributions of maximum range.

9.0 REFERENCES

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